UCRL- 94855
PREPRINT

Comparison Of Numerical Helical Generator Simulations With Experimental Results

D. K. Abe
J. B. Chase

This paper was prepared for submittal to
Megagauss IIII Conference
Santa Fe, New Mexico
July 14-17, 1986

July 1986

Lawrence Livermore National Laboratory

DISCLAIMER

COMPARISON OF NUMERICAL HELICAL GENERATOR SIMULATIONS WITH EXPERIMENTAL RESULTS*

D. K. Abe and
J. B. Chase

Lawrence Livermore
National Laboratory
Livermore, CA

ABSTRACT

We have made comparisons between the experimental results on small helical flux compression generators, described elsewhere at this conference, and computer simulations. A 2D hydrodynamic computer simulation was used to generate the acceleration profile of the armature of the generators. The electrical behavior of the generators was predicted using the CIRC computer code. Various generator loss models were examined, including resistive and flux trapping models. A discussion of the comparisons will be given.

INTRODUCTION

CIRC is a simple 1-1/2 D computer simulation code that has been written to model a small (< 600 cm^3) helical flux compression generator[1]. Although simplifying assumptions were made, the code does take into account the acceleration due to high explosives detonation, temperature effects, flux loss due to conductor resistance, and deceleration due to magnetic pressure. Various lumped electrical circuit elements may be coupled to the generator circuit model.

To evaluate the accuracy of the model, a series of experiments involving the generator and a variety of constant impedance loads has been carried out. Electrical and radiographic data were taken and compared to the CIRC predictions. A description of the experiments and details about the helical generator are presented elsewhere in these proceedings[2].

Hydrodynamic Modeling

The generator is shown in Fig. 1. The hydrodynamic portion of CIRC, which accelerates the armature outward, was verified both by comparison to the results of a large 2D Eulerian hydrodynamic code and by comparison to flash radiographs from experiments. The CIRC hydrodynamic model was then normalized to the radiographic data.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

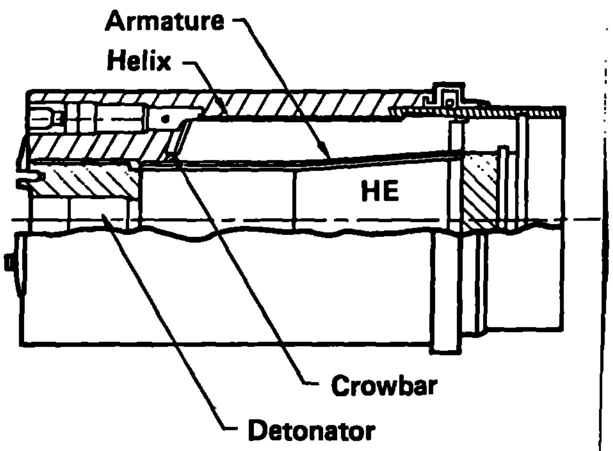

Figure 1. Four stage helical flux compression generator.

Comparison With Experiment

Inductive Loads. A helical generator with a 50 nH inductive load was fired in air. Figures 2 and 3 compare the experimentally obtained output current and di/dt with the CIRC predicted output.

There are a number of discrepancies between the code prediction and the experiment. In all cases, the predicted peak values are high when compared to the data and there is a time shift between the predicted and observed peak times. Also, the CIRC di/dt waveform contains much more structure than the observed waveform. This structure is particularly pronounced at the points where the armature contacts a coil bifurcation point, as evidenced by the local minima in the di/dt waveforms.

The predicted times between successive armature/bifurcation contacts agree quite well with the observed times. This was expected since the hydrodynamic portion of the code was normalized to experimental data. However, the differences in absolute timing between CIRC and the experiments are anomalous.

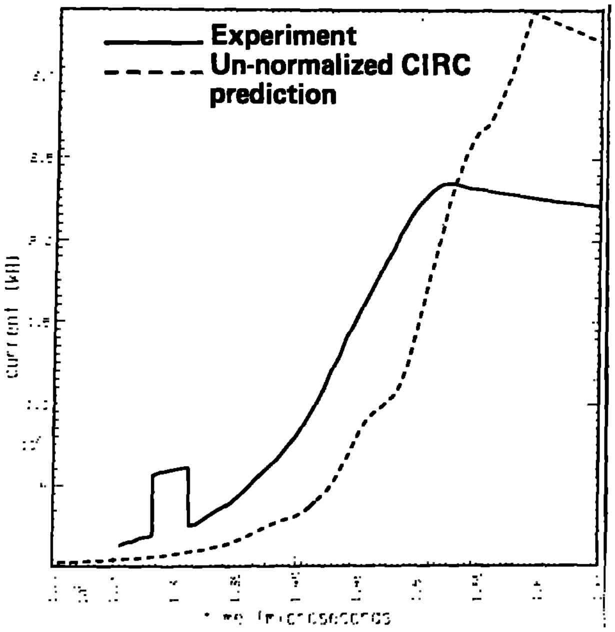

Figure 2. Experimental and predicted current — 50 nH load.

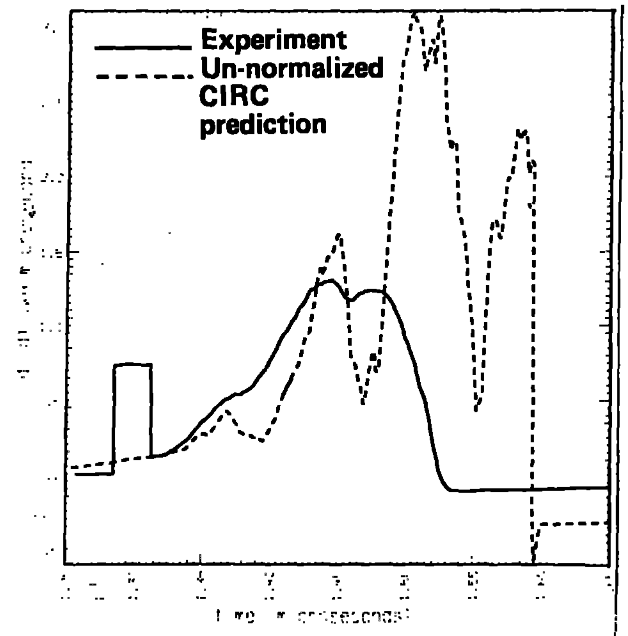

Figure 3. Experimental and predicted di/dt — 50 nH load.

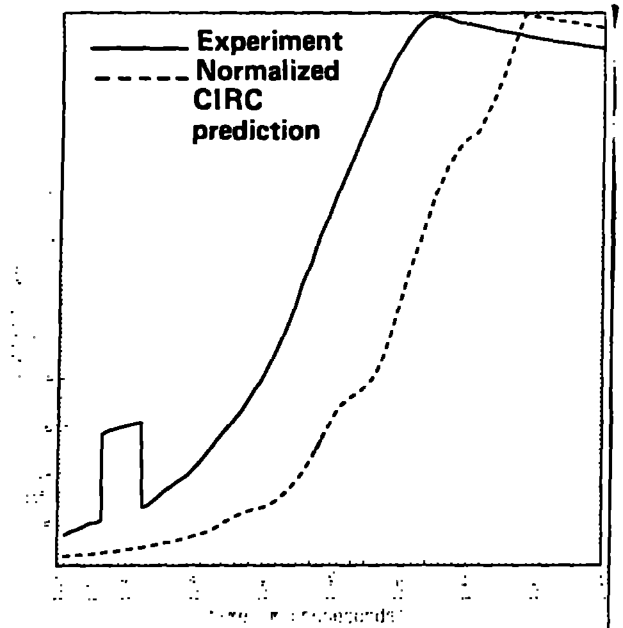

Figure 4. Experimental and normalized predicted current — 50 nH load.

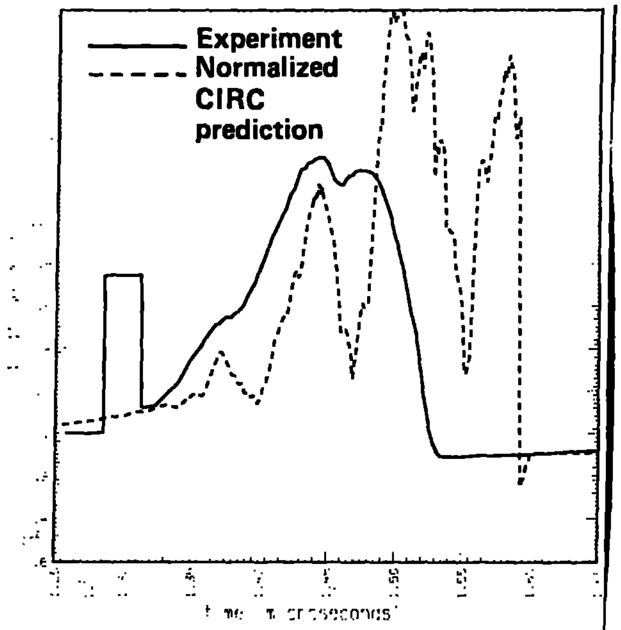

Figure 5. Experimental and normalized predicted di/dt — 50 nH load.

Three different loss models were introduced into the CIRC generator model in an attempt to bring the amplitudes of the experiment and the model into closer agreement. Each loss model was implemented independent of the others. In one loss model, the resistivity of copper in the CIRC equation of state was multiplied by a constant factor until the predicted peak current agreed with experiment. A continuous flux trapping model created an armature/stator contact point ahead of the hydrodynamic contact point, continuously trapping and eliminating the stored magnetic energy in the volume between the two contact points. Finally, a single shot flux trapping model was considered in which flux was trapped and eliminated only once during the code run.

All three loss models brought the CIRC predicted output in closer agreement with the data. The increased conductor resistance model and the continuous flux trapping model yielded similar results. This result was not unexpected as both models produce similar loss terms in the electrical circuit equation for the generator. The single shot flux trapping model was discarded because an unrealistic amount of flux had to be eliminated to make the model agree with the data. Figures 4 and 5 compare the experimentally obtained current and di/dt for a shorted load shot with the normalized CIRC prediction (using the increased conductor resistance loss model).

While both of the loss models were able to bring the computed peak currents in close agreement with the observed data, there are still unaccounted for discrepancies between the computer simulation and the experiment. As can be seen in Fig. 5, the amplitude and shape of the CIRC generated di/dt waveform is drastically different from the data and the observed current still reaches its peak value before the computed current.

It was postulated that the explosively expanding armature moves fast enough to heat and ionize the air in front of it, forming a quasi-conductive layer which contacts the stator ahead of the armature. This might account for both the timing differences between the simulation (which did not have an air ionization model) and the experiment, and for the differences in output amplitude, as a quasi-conductive region might dissipate power in ohmic heat.

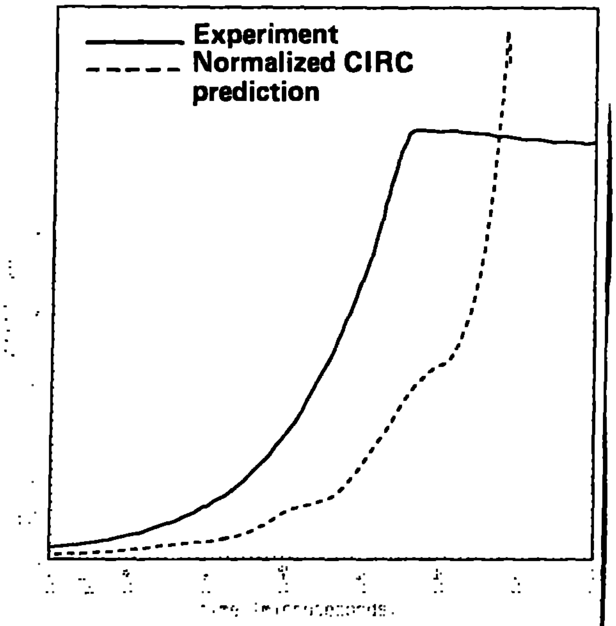

Figure 6. Experimental and normalized predicted current — short circuit load.

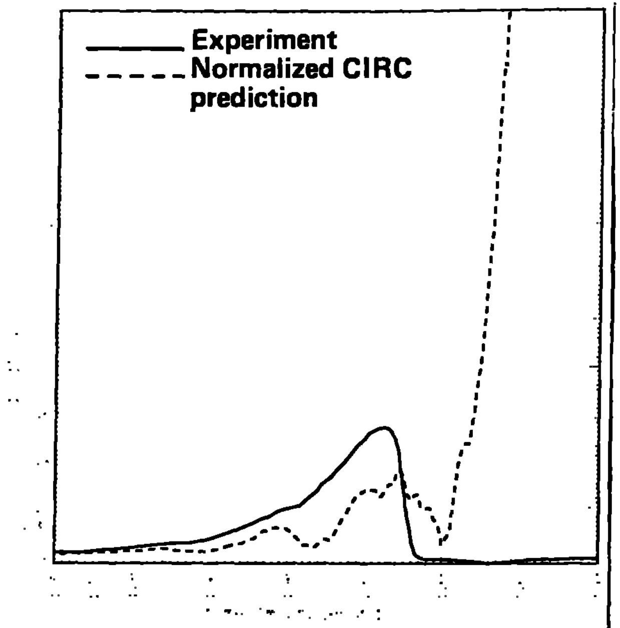

Figure 7. Experimental and normalized predicted di/dt — short circuit load.

To study the effect of trapped air in the generator, a second 50 nH inductive load experiment was performed in a gaseous methane environment. Methane was chosen for its high heat capacity in order to inhibit gas ionization. The results of this test, however, were very similar to the air filled inductive load test and we must conclude that air ionization has little effect on the performance of our generator.

Short Circuit Loads. A number of tests were conducted with the generator terminated in a short circuit[2]. A CIRC simulation of a short circuit experiment was run with the increased conductor resistance loss model normalized to the inductive load data.

Figures 6 and 7 compare the CIRC predictions with the experimental results. The CIRC di/dt waveform does contain features that are seen in the data - the predicted relative amplitudes of the local maxima and the relative timing between minima agree with the experiment. As before, however, the predicted absolute amplitudes of both the current and di/dt waveforms are high, the shape of the predicted di/dt waveform has structure that is not seen in the data and the predicted timing is late compared to experiment.

Resistive Loads. Three generator experiments were fired with purely resistive load terminations. Two shots were terminated in 100 milliohms and one shot was terminated in 25 milliohms. The 100 milliohm shots had apparent internal voltage breakdown problems, so only the 25 milliohm shot was modeled with CIRC.

Figures 8 and 9 compare the predicted and observed current and di/dt waveforms. As with the short circuit simulation, the increased conductor resistance loss model normalized to the inductive load test was used. Once again, CIRC was able to predict the relative peak amplitudes and relative timing, but was unable to accurately predict absolute amplitudes and timing.

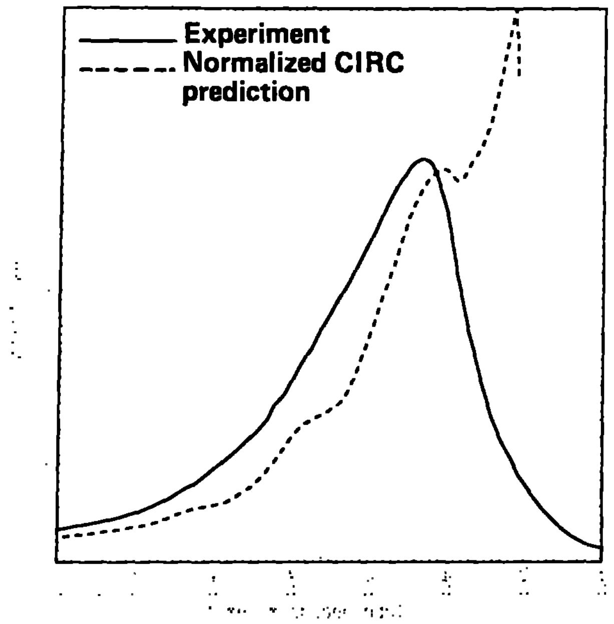

Figure 8. Experimental and normalized predicted current — 25 mΩ load.

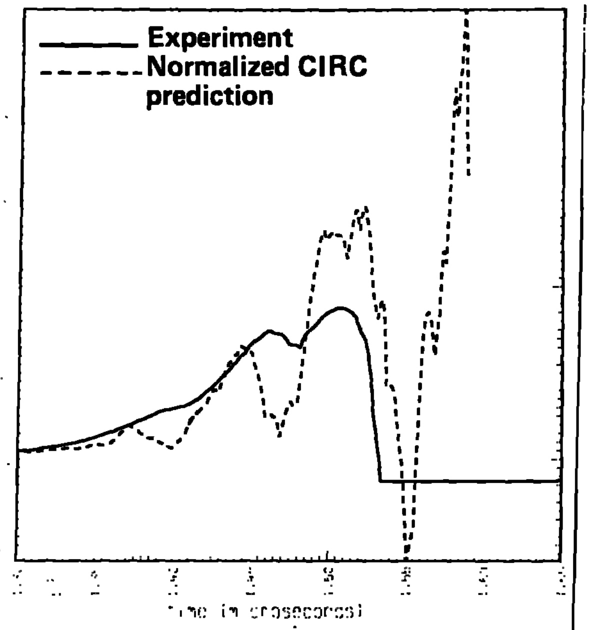

Figure 9. Experimental and normalized predicted di/dt — 25 mΩ load.

Summary

We have compared the results of several experiments involving a small helical flux compression generator and the predictions made by CIRC, a simple computer simulation code. The hydrodynamic portion of the code was verified both by flash radiographic data and by an external 2D code.

In order to bring the code in closer agreement with the electrical data, an anomalous loss model had to be added to the CIRC generator model. A resistive loss model and a flux trapping loss model were considered, with similar results. With the addition of a simple loss model, CIRC was able to predict relative peak amplitudes and relative timing but failed to accurately predict absolute values and waveshapes. The CIRC generator model with loss can be normalized to yield accurate current amplitudes for a given type of load, but the normalization does not necessarily extend to experiments with different electrical terminations.

The observed timing always precedes the predicted timing, even though the hydrodynamic model in the code has been verified by experiment. This suggests that electrical contact to the stator is being made ahead of the armature contact point. It was thought that hot, ionized gases pushed ahead of the moving armature formed a quasi-conductive layer and were responsible for the anomalous timing and losses. However, an experiment in a methane gas environment disproved this theory. Other experiments are being planned to explore other theories.

A number of simplifying assumptions were made in creating the CIRC generator model. We have found that the model has some use in simulating general trends and relative timing for a variety of loads but does not predict absolute performance well. A more detailed model, with less assumptions, is under development and is reported in these proceedings[3].

<u>References</u>

1. J. B. Chase and D. K. Abe, "CIRC - A Simple Helical Flux Compression Generator Computer Code", to be published in the proceedings of this conference.

2. D. K. Abe and J. B. Chase, "Experiments With Small Helical Flux Compression Generators", to be published in the proceedings of this conference.

3. R. E. Tipton, "A 2D Lagrange MHD Code", to be published in the proceedings of this conference.